MODELING OF SEDIMENT YIELD IN A SMALL AGRICULTURAL WATERSHED WITH KINEROS2

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Sediment is a major pollutant of stream waters and serves as carriers for various pesticides, radioactive materials and nutrients. Therefore, development and implementation of BMPs to achieve sediment TMDL targets must be given high priority. The use of distributed hydrologic models has gained wide acceptance in this regard. KINEROS2 is one of those distributed models whose physically-based nature attracts more researchers lately. In this study, the sensitivity of KINEROS2 to model parameters was evaluated by performing Monte Carlo simulations. A small USDA experimental watershed was employed for this purpose. The probability distributions of sediment discharges at various time steps were generated and are used to interpret uncertainties in observed data at the watershed outlet. Model was calibrated for 3 selected events and verified over 4 other events by implementing results of the sensitivity analysis.
KEY TERMS: Sediment, distributed models, sensitivity, Monte Carlo simulations, calibration.

INTRODUCTION

The use of distributed hydrologic models in estimating sediment yield and developing methodologies for achieving TMDL goals such as source assessment (Kalin et al., 2002) becomes more widespread. Calibration, a very time demanding process, is a prerequisite before using complex models with many parameters (Christiaens and Feyen, 2002). Most physically based and distributed models require enormous amount of input data. Although some parameters play crucial roles, some have minimal effect on model results. Therefore, it is a common practice to perform sensitivity analysis before calibrating model parameters. This way the number of parameters to be calibrated can be reduced drastically and only most sensitive parameters are calibrated while average values can be used for the rest of the parameters. The sensitivity of KINEROS2 to various input parameters was evaluated through Monte Carlo (MC) simulations. Based on the sensitivity analysis the model parameters were calibrated and then validated over several events.

Data and Model Parameters

A small USDA experimental watershed (W-2) located near Treynor, Iowa having an area of 83 acres was employed in this study (Figure 1). Measurements of runoff and sediment load are available. There are two rain gauges (115 and 116) around the watershed. W-2 has a rolling topography defined by gently sloping ridges, steep side slopes, and alluvial valleys with incised channels that normally end at an active gully head, typical of the deep loess soil in MLRA 107 (Kramer et al., 1990). Slopes usually change from 2 to 4 percent on the ridges and valleys and 12 to 16 percent on the side slopes. An average slope of about 8.4 percent is estimated, using first-order soil survey maps. The major soil types are well drained Typic Hapludolls, Typic Udorthents, and Cumulic Hapludolls (Marshall-Monona-Ida and Napier series), classified as fine-silty, mixed, mesics. The surface soils consist of silt loam (SL) and silty clay loam (SCL) textures that are very prone to erosion, requiring suitable conservation practices to prevent soil loss (Chung et al., 1999). Corn has been grown continuously on W-2 since 1964.

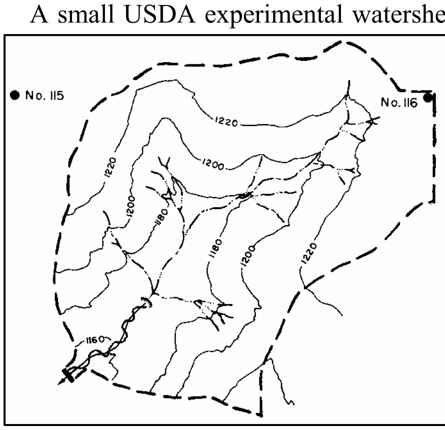

Figure 1. Schematic of W-2.

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Sensitivity Analysis and MC Simulations

Sensitivity of KINEROS2 was performed over the parameters listed in Table 1. In the table K_s is saturated conductivity, λ is pore size distribution index, Ψ_b is bubbling pressure, G is net capillary drive, POR is porosity, S_i is initial saturation, n_{ch} and n_p are channel and plane Manning's roughness, respectively, Inter is the interception depth, CAN is canopy percentage, C_g is cohesion coefficient, c_f is rainsplash coefficient and d_{50} is the mean particle diameter. One thousand random values were generated for each parameter. The ranges of parameters from which the random numbers were generated are shown in the table for two soil types (SL and SCL). KINEROS manual (Woolhiser et al., 1990) suggests values and puts limits for C_g and C_f. During calibration, however, we found values outside the margins. In a similar study, Smith et al. (1999) estimated even larger values for these two parameters during the calibration of Catsop Catchment. After confirming with one of the model developers (C. Unkrich, personal communication) it was decided not to limit ourselves to the values given in the manual. The random values for the parameters K_s, λ, Ψ_b and POR were generated from log-normal distributions using IMSL routine, where the corresponding mean and standard deviations are given respectively in parentheses in Table 1. The parameter Ψ_b is not required by KINEROS2 but we used it to generate random G values which is given by the relationship $G=\Psi_b(2+3\lambda)/(1+3\lambda)$ based on Brooks-Corey model. It is striking that the suggested G values in the KINEROS2 manual are much smaller than the values generated this way. The rest of the parameters were generated from uniform distributions.

Table 1. Input parameters of KINEROS-2.

	K_s (mm/hr) [a]	λ [b]	Ψ_b (cm) [c]	G (cm) [d]	POR [b]	S_i [b]	n_{ch} [x]
SL	log(4.5,12.3)	log(0.23,0.13)	log(51,59)	0.2-694	log(0.50,.08)	0.03-0.97	0.01-1.00
SCL	log(0.7,1.9)	log(0.18,0.14)	log(70,74)	0.7-7380	log(0.47,.05)	0.08-0.92	

	n_p [x]	Inter [x]	CAN [x]	C_g [x]	C_f [x]	d_{50} (μm) [b]
SL	0.01-1.01	0-3.0	0-1.0	0.01-1.00	100-1000	3-50
SCL				0.01-1.00	100-1000	

A US EPA/600/R-93/046, 1993. PRIZM-2 Users Manual for Release 2.0
B KINEROS Manual (Woolhiser et al., 1990)
C Rawls et al., 1982
D From $G=\Psi_b(2+3\lambda)/(1+3\lambda)$
X Randomly decided

A random rainfall event was picked that occurred on 6/13/1983 with a total rainfall depth of 48 mm. MC simulations were performed with this event for each parameter by running KINEROS2. Peak flow (q_p), cumulative flow (q_t), time to peak flow (t_{pf}), peak sediment discharge (q_{sp}), total sediment yield (q_{st}) and time to peak sediment discharge (t_{ps}) values were recorded. Figure 2 and 3 shows results from the MC simulations. Since, our focus is on sediment; only results related to sediment are shown. The horizontal axis in Figure 2.a and 3.a is q_{sp} (kg/s), in 2.b and 3.b is q_{st} (tons) and in 2.c is t_{ps} (min). The vertical axis in each figure shows the exceedance probabilities (1-CDF). Results for less sensitive parameters are not shown. Steeper the slope, less sensitive the parameter is. Results are almost insensitive to λ but it is shown in Figure 2 to represent average conditions. Only parameters shown in Figure 3 are directly affecting sediment transport. In other words, parameters shown in Figure 2 determine the shape of the hydrograph and since sediment discharge is a function flow, they indirectly affect sedimentograph. MC simulations were performed for an additional, smaller event with a total rainfall depth of 17 mm for c_f and c_g. The secondary axes in Figure 3 correspond to this event. From Figure 2 it is clear that the order of sensitivity is K_s, n_p, G, S_i and n_c when q_{sp} is concerned. When q_{st} is concerned K_s is by far the most sensitive parameter followed by G, S_i and n_p. t_{ps} is most sensitive to n_{ch} and n_p. K_s and G are the next most sensitive parameters. Order of sensitivities may differ depending on the size and the nature of the rainfall event and quantity of interest. For instance, interception depth may play a significant role during small events. However, the general picture is the same. The model sensitivity to c_f and c_g are again event dependent as shown in Figure 3. It is more sensitive to c_g than c_f during large events and more sensitive to c_f than c_g in smaller events. The t_{ps} is totally insensitive to c_f and c_g. During calibration, since flow parameters have to be calibrated first; Manning's roughness should be estimated initially to match hydrograph timings. Next, Ks, G and S_i should be calibrated to adjust the volume of hydrographs. The parameter S_i depends on the antecedent moisture condition and should be adjusted for each event.

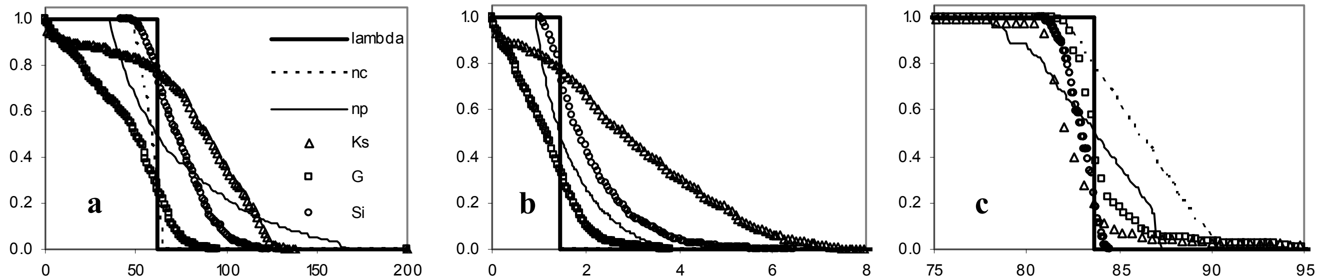

Figure 2. Probability of exceedance of a) Peak sediment discharge (kg/s) b) Total sediment yield (tons) and c) Time to peak sediment discharge (min) for some selected parameters.

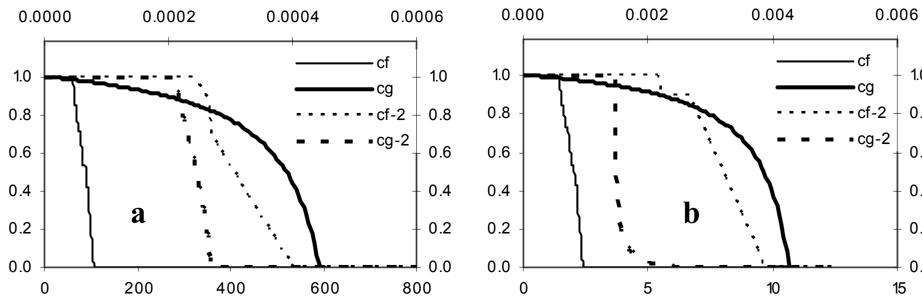

Figure 3. Probability of exceedance of a) Peak sediment discharge (kg/s) and b) Total sediment yield (tons) to c_f and c_g parameters. Secondary axes are for c_f-2 and c_g-2 (second event).

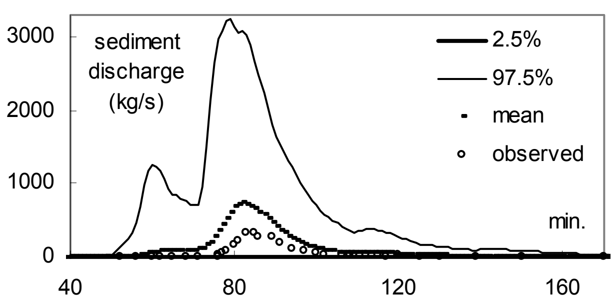

Figure 4. Range of generated sediment discharges for the event 6/13/1983.

One thousand set of the randomly generated values for all parameters were formed. KINEROS2 was run for each set of parameter with 3 different events. At each time step (1 min) the computed sediment discharges were ranked from smallest to largest. The 25th (97.5 %) and 975th (2.5 %) largest values were plotted in the same graph with observed values. We can expect 95 % of the observed values fall in this band. As an example the event 6/13/1983 is shown in Figure 4. In addition to 2.5 % and 97.5 % values, mean values are also shown in the figure. All of the observed values fall within the band as expected which is the case for the other events too. This gives us confidence that the model performs properly and can be calibrated with the given ranges of parameters.

Model Calibration, Validation and Discussion

3 events for model calibration and 4 events for model validation were selected. Calibrations were performed manually by comparing computed and observed hydrographs and sedimentographs. Average values were used for G (35,20 cm), λ (0.6,0.6), POR (0.47,0.50) and D_{50} (7 μm). First values in parenthesis are for SL and second values are for SCL. Table 2 shows calibrated parameters. First three events are for calibration and rest is for validation purpsoes. At the end of each row the Nash-Sutcliffe statistics were given for both flow and sediment. For simplicity, same roughness values were used for channels and overland flow planes which were allowed to vary by time of the year due to growing crops. It is assumed lowest at the beginning and largest at the end of the growing season. S_i was allowed to vary from event to event. S_i values were calibrated by taking precipitation fallen during the previous five days into account. Since KINEROS2 does not model evapotranspiration losses, these losses were incorporated into Inter which was also allowed to vary by event and seasonally. The soil erosion parameters c_g and c_f are known to vary from event to event due to sediment availability (Ziegler et al, 2001) and seasonally due to tillages, freeze-thaw processes and change in vegetation (Smith et al., 1999). Therefore, they were allowed to decay exponentially from highest values at beginning of the growing season to lowest at the end of the growing season. They were highest in 5/30/1982 and lowest in 8/26/1981. Negligible differences in K_s values were observed during calibration.

Table 2. Parameter set following calibration.

	n	Ks_{SCL} (mm/hr)	Ks_{SL} (mm/hr)	Inter (mm)	Si_{SCL}	Si_{SL}	cg	cf	$Nash_{flow}$	$Nash_{sed}$
6/13/83	0.055	1.8	6.5	2.0	0.44	0.27	0.15	160		
5/30/82	0.040	1.5	6	0.0	0.90	0.86	0.25	200		
8/26/81	0.080	2.0	7	1.0	0.84	0.60	0.05	100		
6/12/80	0.055	1.8	6.5	2.0	0.44	0.27	0.15	160	0.92	0.83
7/8/81	0.080	5.0	16	3.5	0.24	0.20	0.08	130	0.99	0.91
8/29/75	0.090	2.5	9	2.5	0.34	0.20	0.01	90	0.96	0.93
8/1/81	0.020	3.0	13	4.0	0.24	0.20	0.015	100	0.87	0.84

Parameters estimated using the validation events are, in general, in good agreement with calibrated parameters. There are acceptable amount of variations in K_s values considering the nature of K_s which has very high coefficient of variations in most soils (eg. 2.73 for SL). The only unexpected result is with the n value of the event 8/1/1981. A value of 0.02 is estimated in contrast to an expected value of 0.08 to accommodate the early response observed in measured data. Based on rainfall records soil is expected to be very dry prior to this event. Therefore S_i is kept minimum, and since it is the month of August Inter can not be zero. Possible explanations might be i) potential measurement errors or ii) even at this small scale spatial variation of rainfall may play an important role. The computed and observed sedimentographs are shown in Figure 5.

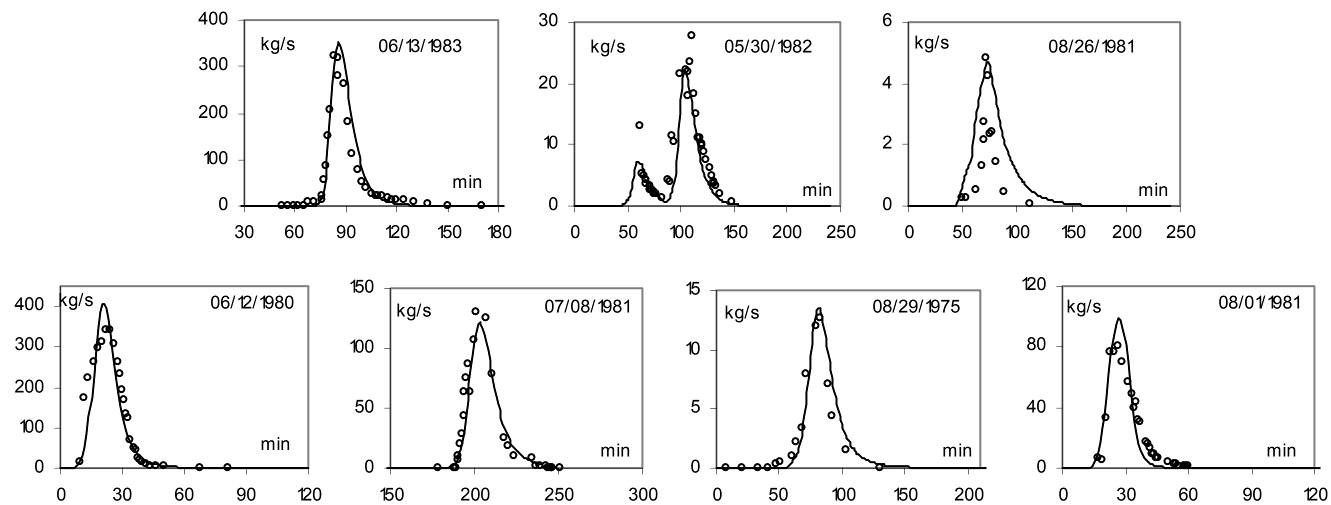

Figure 5. Computed and observed sedimentographs for selected events.

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